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13281 U.S.PTO

Mail Stop Provisional Patent Application

PTO/SB/16 (6-95)
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PROVISIONAL APPLICATION COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION under 37 CFR 1.53 (c).

	Docket Number	2380-816	Type a plus sign (+) inside this box→	+

INVENTOR(S)/APPLICANT(S)

LAST NAME	FIRST NAME	MIDDLE INITIAL	RESIDENCE (CITY AND EITHER STATE OR FOREIGN COUNTRY)
Kallstenius	Thomas		Stockholm, Sweden

031083 U.S. PTO 60/532628 122903

TITLE OF THE INVENTION (280 characters)

ABSOLUTE TIME SYNCHRONIZATION OF NODES IN A UNIDIRECTIONAL FIBER RING

CORRESPONDENCE ADDRESS

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ENCLOSED APPLICATION PARTS *(check all that apply)*

☒ Specification	Number of Pages	13	☐ Applicant claims "small entity" status. ☐ "Small entity" statement attached.
☐ Drawing(s)	Number of Sheets		☐ Other (specify)

METHOD OF PAYMENT *(check one)*

	PROVISIONAL FILING FEE AMOUNT ($)	
☒ A check or money order is enclosed to cover the Provisional filing fees ($160.00)/($80.00) ☒ The Commissioner is hereby authorized to charge any deficiency, or credit any overpayment, in the fee(s) filed, or asserted to be filed, or which should have been filed herewith (or with any paper hereafter filed in this application by this firm) to our Account No. 14-1140. A duplicate copy of this sheet is attached.		160.00

The invention was made by an agency of the United States Government or under a contact with an agency of the United States Government.

☒ No.

☐ Yes, the name of the U.S. Government agency and the Government contract number are:

Respectfully submitted,
SIGNATURE [signature] DATE December 29, 2003

REGISTRATION NO. *(if appropriate)* 33,149

TYPED or PRINTED NAME John R. Lastova

☐ Additional inventors are being named on separately numbered sheets attached hereto.

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1 TECHNICAL INFORMATION

1.1 Name of invention

Absolute time synchronization of nodes in a unidirectional fiber ring

1.2 Inventor(s)

Name : Thomas Kallstenius

1.3 BACKGROUND

Absolute time synchronization, or time-of-day synchronization, of nodes in a distributed network is important for many applications, e.g., scheduling of distributed tasks and to accurately log the occurrence of various events.

In case of the radio access network (RAN), absolute time synchronization is necessary or desirable in many cases:

<u>Soft and softer handover, diversity</u>

Soft and softer handover, and diversity in general, means that a mobile terminal (MT) transmits signals to, and receives signals from, more than one node at a time, as shown in Figure 1. Depending on the architectural level of diversity, the synchronization requirements are different. In case of TX diversity, the time alignment error shall not exceed ¼ T_c [i], which corresponds 65 ns.

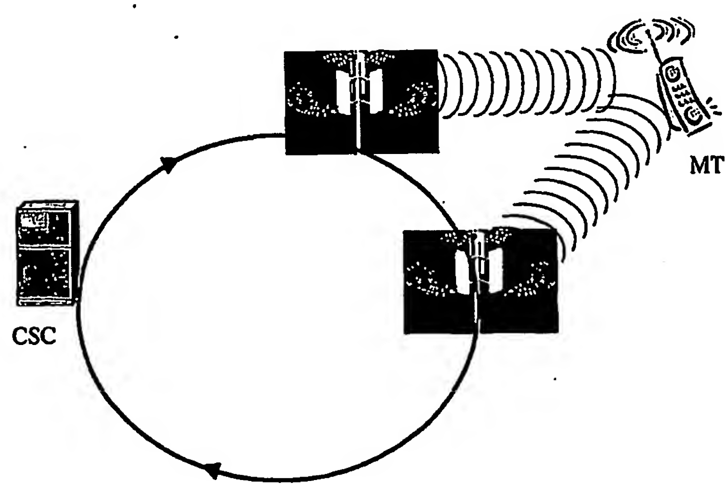


Figure 1:Diversity in a distributed network with a central system clock (CSC) and two nodes connected to a unidirectional fiber ring.

A-GPS positioning

The Global Positioning System (GPS) is a satellite based positioning system, which offers one of the best radio navigation aid currently available. GPS can be combined with cellular applications, which is referred to as assisted GPS (A-GPS). In this case, ~5 μs absolute time accuracy is desirable from a technical standpoint [ii, iii].

Round Trip Time (RTT) Based positioning

RTT measurements can be used to increase the accuracy of cell ID based positioning. The RTT is the propagation time of the signal traveling from the MT to the base station (in our case the CSC) and back, as seen in Figure 2. The accuracy of this measurement should be better than $\pm T_c/2$ ($\pm$ 130 ns) [iv]. Although this is a not an absolute timing requirement, the importance of the present invention for this requirement will be come apparent from text below.

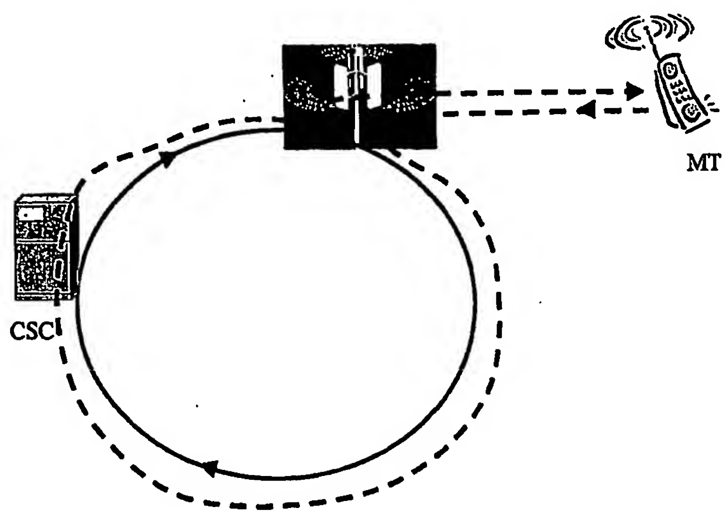


Figure 2:RTT positioning with a CSC and a node connected to a unidirectional fiber ring

Time of Arrival (TOA) positioning

In TOA, the position calculation is based on the propagation delay of the radio signal from the transmitter (the node) to the MT. When there are at least three TOA measurements available from different nodes, together with other information concerning, e.g., geographic position of the nodes, the position of the MT can be carried out by applying a triangulation technique. The absolute time synchronization of the nodes must be done to a level of accuracy of

the order of a few nanoseconds as 10 nanoseconds uncertainty contributes to roughly 3 meters error in the position estimate [v].

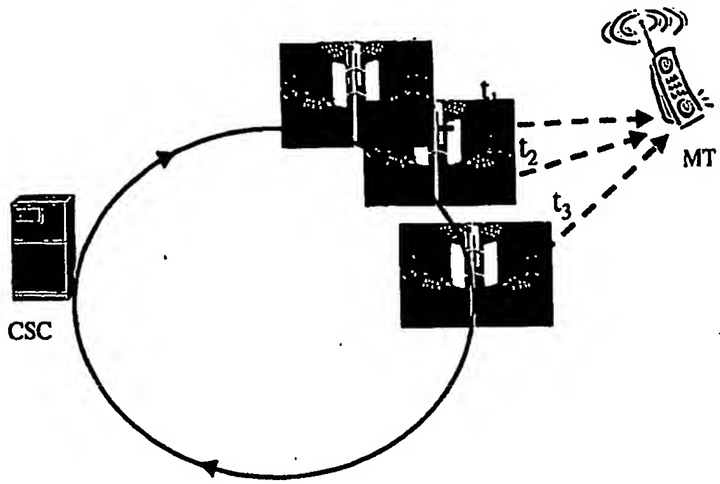


Figure 3:TOA positioning with a CSC and two nodes connected to a unidirectional fiber ring

1.4 Background

In today's RAN, dedicated links are often used for each node. In such a case, frequency synchronization is obtained using clock-recovery method based on phase-locked loop or similar. Absolute time synchronization is also readily achieved by roundtrip delay measurements, using the fact that the uplink (UL) and the downlink (DL) are symmetrical. In case the nodes are hooked onto a network with other traffic, switches/routers etc., GPS synchronization can be used to obtain synchronization in the nodes. This means that each radio base station has a GPS receiver connected to it, or at least in close vicinity. There are several drawbacks of this. Firstly, GPS receivers are expensive, which results in an increased cost of production. Secondly, GPS synchronization may be difficult for indoor systems since the GPS signal cannot penetrate very thick walls and cannot be used in tunnels, subways and similar. Thirdly, some countries may not accept a solution based on GPS since this means that their mobile network can effectively be disabled in case of international tension by other nations controlling the GPS system.

A unidirectional ring is an interesting network topology for two reasons. To begin with, such rings support synchronous time division multiplexed (TDM) traffic without any additional switches, splitters, add-drop multiplexers etc. Synchronous traffic provides inherent frequency synchronization, a characteristic which is important for the RAN. In addition, unidirectional rings require a minimum of transceivers in the network nodes. Only one receiver and one transmitter are required in each node connected to the ring.

1.5 PROBLEM

A general problem with unidirectional rings is absolute time synchronization. The frequency synchronization can be achieved by means of standard clock-recovery method but it is not possible to absolute time synchronize individual nodes using roundtrip measurements, for example.

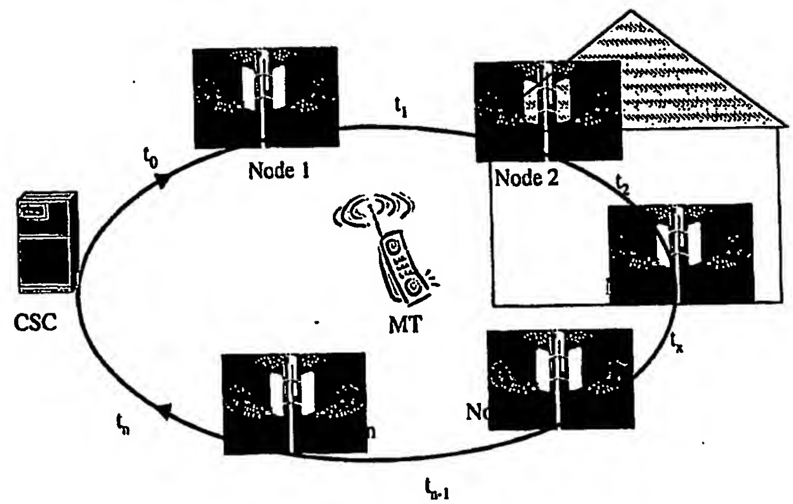


Figure 4: Distributed nodes in a unidirectional ring configuration. The mobile terminal (MT) is communicating with a multiple of nodes for diversity and positioning services. The nodes are frequency and absolute time synchronized to the CSC. Link 2 is located indoors, other links are outside.

1.6 SOLUTION

The present invention addresses absolute synchronization in a unidirectional ring topology based on fiber. The invention is based on Optical Time Domain Reflectometry (OTDR), in combination with round-trip delay corrections.

During installation of the nodes, OTDR is used to determine the fiber link distance between the nodes. An OTDR uses a light backscattering technique to analyze fibers. In essence, it takes a snapshot of the fiber's optical characteristics by sending a high-powered pulse into one end of the fiber and measuring the light

scattered back toward the instrument. OTDR is often used during fiber installation to detect faults in the fibers, and use complex computations to determine the size and distance to events encountered in the fiber run. OTDR can be used to determine the fiber length with accuracy less than 1m, corresponding 5 ns resolution in the time domain. This is promising, considering the absolute time synchronization requirements of a few nanoseconds mentioned.

The measured fiber delays are stored in the CSC, to be used for absolute time synchronization. A potential problem with the unidirectional ring, in this respect, is the influence of temperature on the fiber delay. For many other topologies, roundtrip delay measurements towards the nodes can be used to continuously measure and account for variations in the fiber delay. In a unidirectional ring, roundtrip measurements cannot generally by used to estimate the fiber delay towards a node since the UL and DL are generally not symmetrical. Therefore, a method for temperature compensation may be necessary in order not to jeopardize the absolute time accuracy of some nanoseconds. The present invention suggests to use a method based on calculated correction factors for each node, using variations in the roundtrip delay measurement as a probe of the temperature variations. The method takes into account that some links are affected by temperature variations more than others. The former may be links outside and the latter links indoors, as depicted in Figure 4.

The change in time-of-flight (TOF) with temperature is caused by two effects: firstly the temperature dependence of the group index and secondly the change in physical length with temperature. A theoretical estimation of the TOF change at 1310 nm, with a group index of 1.467, is 75 ps/°C/km [vi]. The change in length and group index each contribute approximately equally to this value. Consider a unidirectional ring of 50 km in circumference. If the entire absolute time synchronization budget of, say, 10 ns can be allocated for this purpose, a temperature variation of 3°C should be acceptable:

$$10 \text{ ns} = 75 \text{ps/°C/km} \cdot 50 \text{km} \cdot \Delta T \Rightarrow \Delta T = 3°\text{C}$$

The present invention relates to providing higher absolute time accuracy by means of a temperature compensation method. Three embodiments are described. In the first case, "Synchronization of nodes", all nodes in the ring are absolute time synchronized. In the second case, "Centralized delay compensation in the CSC", the CSC keeps track of absolute time deviations of the nodes. This case is interesting since absolute time deviations are often acceptable as long as they are well known. No adjustments of the nodes is necessary in this case, which prevents time transients that may cause various types of problems at different levels of the protocol stack.

Finally, the RTT positioning is described in a separate case in Section 1.6.3.

1.6.1 Synchronization of nodes

In this case, the CSC measures the roundtrip delay of the unidirectional ring and sends time estimates to each node, based on continuous roundtrip measurement and OTDR measurements during installation.

Installation and initial synchronization:

During installation of the nodes, OTDR is used to determine the fiber delay for each link, t_i, for the present temperature. At the same time, the roundtrip time is measured to obtain an average value:

$$\overline{t_{RTD}} = \sum_{i=0}^{n} t_i + n \cdot t_{process} \tag{1}$$

, where n is the number of nodes, $t_{process}$ is the processing time in each node.

Synchronization messages, M_x, can now be sent from the CSC to each node x to obtain an absolute time synchronization:

$$M_x \left\{ t_x = t_{CSC} + \sum_{i=0}^{x-1} t_i + (x-1) \cdot t_{process} \right\} \tag{2}$$

, where M_x is the message from the CSC to node x; t_x is the local time in node x, as imposed by the CSC; t_{CSC} is the local time in the CSC upon dispatch.

Synchronization at later stage:

At later stage, the absolute time synchronization needs to be updated. To begin with, the CSC measures the roundtrip time again:

$$\overline{t'_{RTD}} = \sum_{i=0}^{n} t_i (1 + \varepsilon_i) + n \cdot t_{process} \tag{3}$$

, where ε_i is a factor which takes the effect of temperature on the fiber delay (t_i refers to the fiber delays obtained by OTDR during installation). Now, let's separate the links into two rough categories: links subjected to and not subjected to substantial temperature variations. Let the former be labeled "affected" and the latter "unaffected":

$$\overline{t'_{RTD}} = \sum_{i=0,unaffected}^{n} t_i + (1+\varepsilon) \sum_{i=0,affected}^{n} t_i + n \cdot t_{process} \tag{4}$$

, where we have assumed that links affected by temperature variations are affected approximately by the same delay factor ε. From Eqs. (1) and (4), ε can be calculated as

$$\varepsilon = \left[\overline{t'_{RTD}} - \overline{t_{RTD}}\right] \Big/ \sum_{i=0,affected}^{n} t_i \tag{5}$$

Accordingly, modified synchronization messages, M'_x, can now be sent from the CSC to each node x to obtain an absolute time synchronization:

$$M'_x\left\{t_x = t_{CSC} + \sum_{i=0,unaffected}^{x-1} t_i + (1+\varepsilon) \sum_{i=0,affected}^{x-1} t_i + (x-1) \cdot t_{process}\right\}$$

$$\Rightarrow \tag{6}$$

$$M'_x\left\{t_x = t_{CSC} + \sum_{i=0}^{x-1} t_i + C_X + (x-1) \cdot t_{process}\right\}$$

where C_x is a correction term of the original synchronization message (see Eq. (4)), which can be expressed as:

$$C_X = \left[\overline{t'_{RTD}} - \overline{t_{RTD}}\right] \cdot \left[\sum_{i=0}^{x-1} t_i \Big/ \sum_{i=0}^{n} t_i\right]_{affected} \tag{7}$$

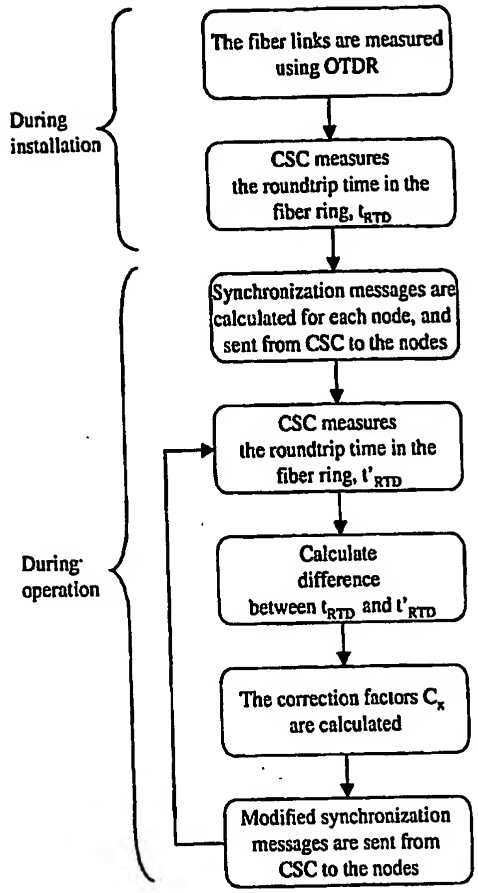


Figure 5: Flow chart describing node synchronization

1.6.2 Centralized delay compensation in the CSC

As an alternative, the nodes can send in local time estimates to the CSC, which then calculates the offset between the absolute time in the node x and the CSC:

$$t_x = t_{CSC} + \delta_x \tag{8}$$

where t_x is the local time in node x and δ_x is the time difference between node x and the CSC.

Using similar arguments as in the previous section, it can be shown that

$$\delta_x = \sum_{i=x}^{n} t_i + D_X + (n-x)\cdot t_{process} - \Delta t_x \tag{9}$$

, where Δt_x is the time difference between the local time in the CSC upon receipt of the timestamp message $m_x(t_x)$ from node x, as measured by the CSC:

$$\Delta t_x = t_{CSC} - m_x \tag{10}$$

D_x is a correction term, which is slightly different from C_x:

$$D_x = \left[\overline{t'_{RTD}} - \overline{t_{RTD}}\right] \cdot \left[\sum_{i=x}^{n} t_i \Big/ \sum_{i=0}^{n} t_i\right]_{affected} \tag{11}$$

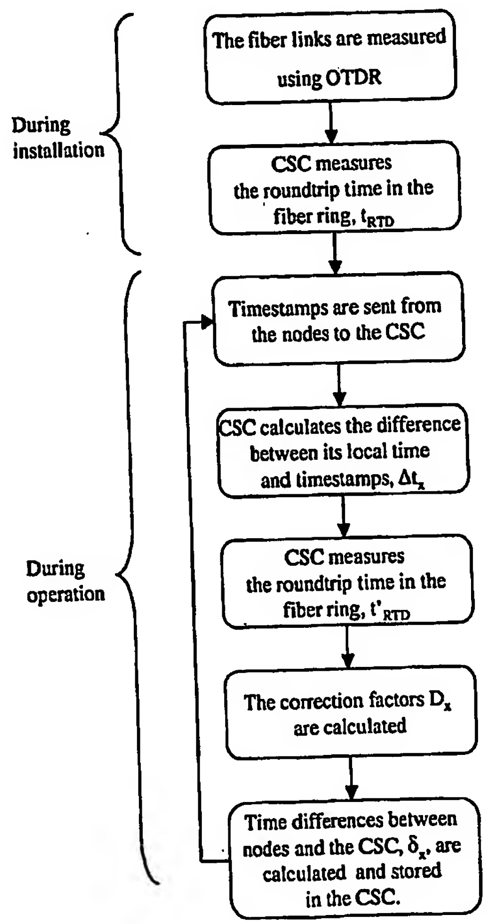


Figure 6: Flow chart delay compensation in the CSC

1.6.3 Temperature compensation for RTT positioning

The ring topology in itself does not impose any additional constraints in case of RTT positioning. Reason for this is that the UL and DL paths in air can be assumed to be symmetrical, and as long as other delay components in the delay chain do not change the overall roundtrip delay from the MT to the CSC and back, they do not need to be symmetrical. This is illustrated in Figure 2. But they must be well known, with accuracy much better than $\pm T_c/2$, say $T_c/4$. In order to meet this requirement, temperature effects on the fiber

delay must be taken care of. Consider a ring topology of 50 km ring in of 50 km in circumference:

$$T_c/4 = 65 \text{ ns} = 75\text{ps}/^\circ\text{C/km}\cdot 50\text{km}\cdot \Delta T \Rightarrow \Delta T = 17^\circ\text{C}$$

According to this, a temperature change of 17°C may jeopardize the required accuracy. The temperature effect can be compensated for if the CSC continuously measures the roundtrip delay in the ring. This is illustrated in Figure 7 below. The most recent roundtrip delay value in the fiber ring, as measured by CSC, is subtracted from the overall roundtrip time from the MT to the CSC and back. Such compensation can be performed in, e.g., the MS or in the CSC. The latter is shown in Figure 7. It should be noted OTDR is not necessary in this case.

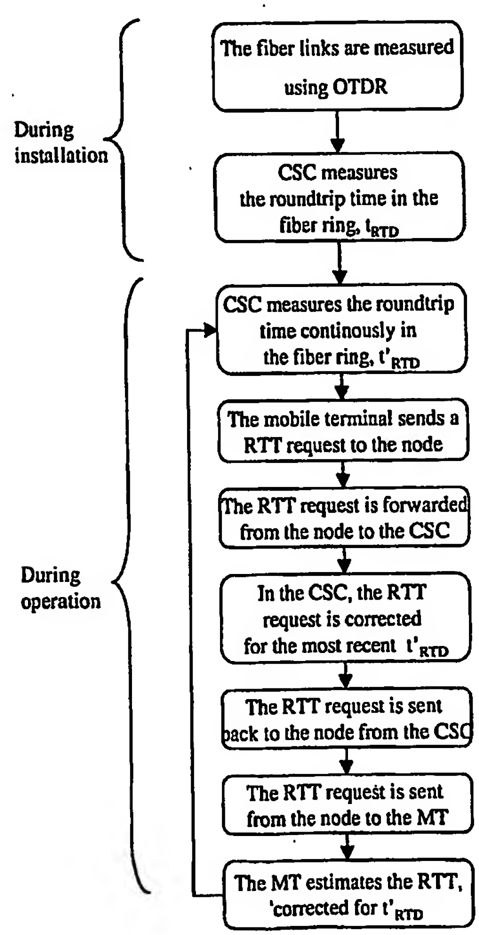
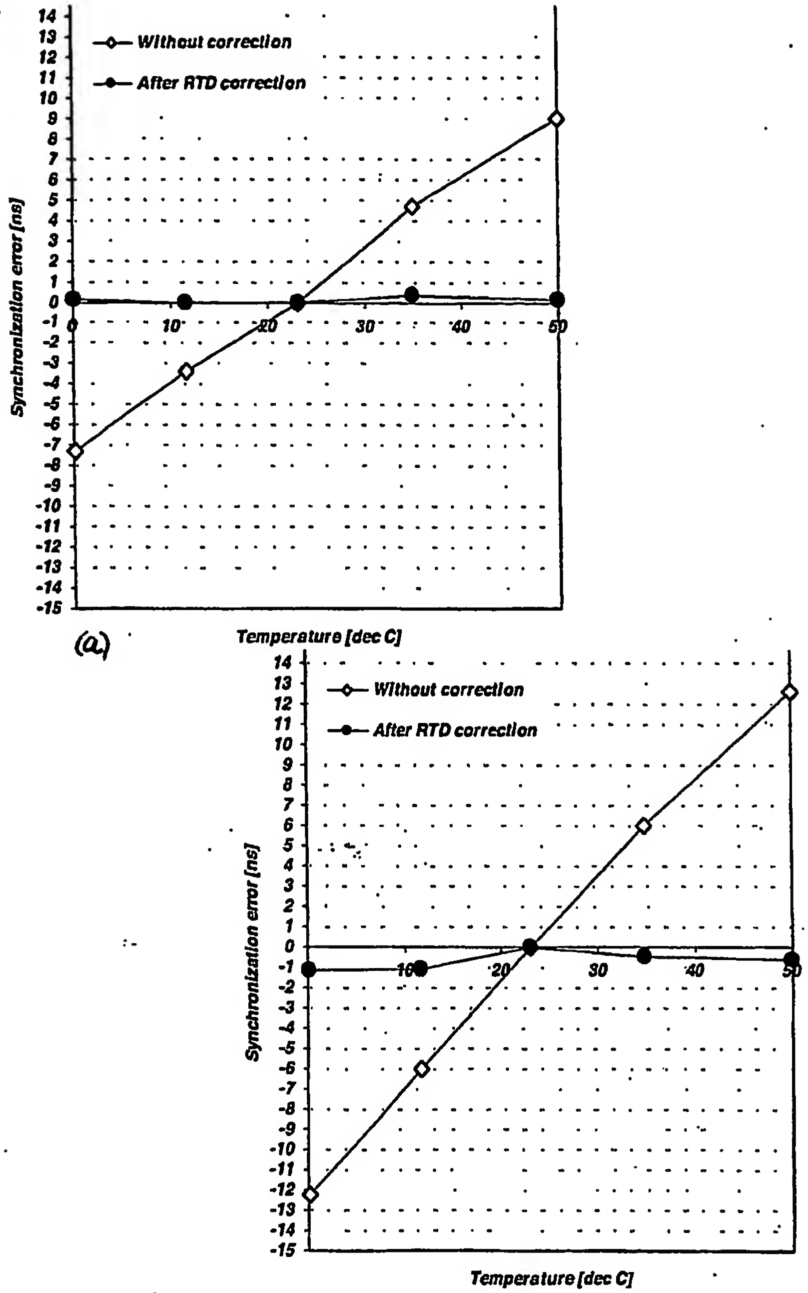


Figure 7: Flow chart delay RTT positioning

1.7 Merits of the invention

The invention provides means for absolute time synchronization of nodes in a unidirectional fiber ring topology. This important for a number of different applications and services, the RAN being one important example. The accuracy of the synchronization is acceptable for all presently known services in the UMTS environment. Merits of the invention are illustrated in Figure 8. The figure shows experimentally obtained synchronization errors in a unidirectional ring due to temperature variations, with and without using the temperature compensation scheme of the present invention. As seen in this Figure, the temperature-induced error was often more than 10 ns for the second node if no compensation was applied. The use of the temperature compensation resulted in an error smaller than 1 ns in most cases, i.e., a factor better 10 roughly.



(b)

Figure 8: Synchronization error vs. temperature before and after roundtrip delay correction for (a) node 1 and (b) node 2

1.8 Patentable feature/ claims

A patent should first and foremost protect the idea of using roundtrip delay measurements as a probe of temperature differences along the unidirectional fiber ring. Secondly, we should try to protect this in

combination with OTDR and then the specific embodiments of the invention as described in Sections 1.6.1-1.6.3. The following claim-structure is an attempt to show this logical structure:

Claim 1: Roundtrip delay measurements in a unidirectional fiber ring for detection of temperature induced delay variations (see Section 1.6).

Claim 2: Claim 1, wherein some parts of the fiber ring is subjected to considerable temperature differences whereas other parts are not (see Section 1.6).

Claim 3: Claim 1 (and Claim 2), in combination with OTDR synchronization for absolute time synchronization (see Section 1.6).

Claim 4: Claim 3, wherein each node in a unidirectional ring topology is absolute time synchronized relative to a CSC (see Section 1.6.1).

Claim 5: Claim 3, wherein the CSC keeps track of the absolute time offsets between the each node and the CSC (see Section 1.6.2).

Claim 6: Claim 1 (and Claim 2), wherein the most recent roundtrip delay is used to correct RTT positioning estimates for temperature induced delay variations (see Section 1.6.3).

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[i] 3GPP TS 25.104 V5.7.0 (2003-06), section 6.8.4
[ii] Scott Bloebaum, The Ericsson GPS Solution for Location Services in Cellular Networks, EUS/TF-99:5068/REP June 12, 2000 (Rev. B)
[iii] 3GPP TS 25.133 V5.7.0 (2003-06), section 9.2.10
[iv] 3GPP TS 25.133 V5.7.0 (2003-06), section 9.2.8.1
[v] 3GPP TS 25.305 V5.4.0 (2002-03), section 9.2
[vi] HL/ECA/NT/OB Johan Jason, "Temperature dependence of the time of flight in optical fibres", ECA/NT/OB-00:133 Uen, 2000-08-28, rev. PA1

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